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ORIENTED RUTILE IN A HIGH-TEMPERATURE ANDESINE FROM NIGERIA

By P. M. GAME

(*With Plate* 5)

The rock

In 1942 Dr. J. R. F. Joyce collected two specimens of an anorthoclase-trachyte from a low hill near Ropp in the Plateau Province of central Nigeria. One of these was presented to the Museum in 1949 (registered number B.M. 1949,25). This rock is chiefly remarkable for the very large phenocrysts of anorthoclase which are described in the following note. Xenoliths and xenocrysts of several different types occur, including a 'glomero-porphyritic' group of twinned plagioclase which is roughly elliptical in shape and measures 13×9 mm. This plagioclase shows a narrow but conspicuous reaction rim, and many of the grains of the group contain oriented rod-like inclusions. The composition of the host and of its reaction rim, the type of twinning, and the orientation of the inclusions were determined by measurements on a Leitz universal stage.

The host

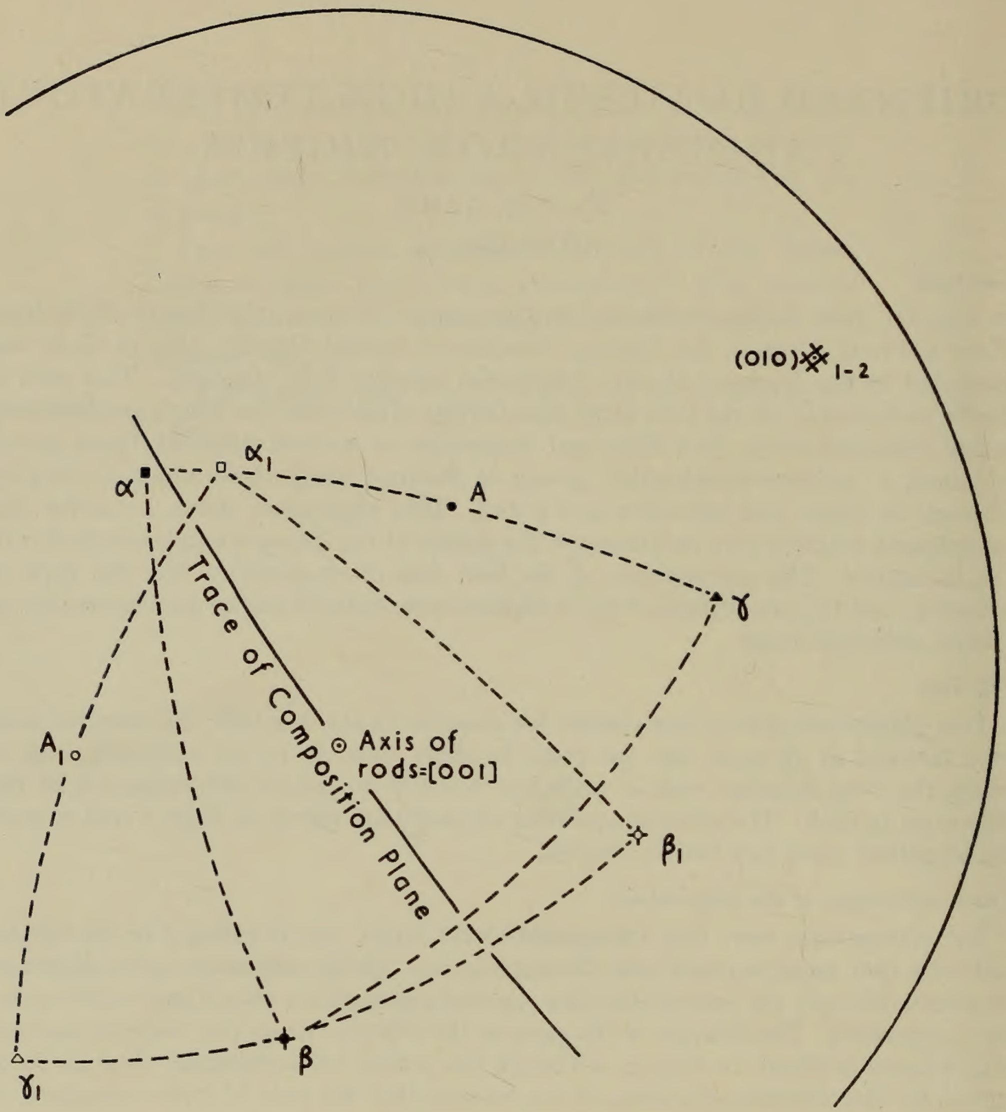
Two plagioclase grains were chosen for measurements in which the oriented rods were inclined at an angle not too great to allow them to be set vertically, and in which the twin lamellae were of sufficient breadth to permit determination of the indicatrix in each. The stereograms thus obtained are shown in Figs. 1 and 2, with the identified poles (see below) labelled.

The composition of the plagioclase

The stereograms were first transposed in the usual way bringing β to the centre, and were then superimposed over the appropriate Nikitin migration curve diagram[1] in order to identify the poles of the cleavage and composition planes and to determine the composition. The relation of the poles to the Nikitin curves (for low-temperature plagioclases) is shown in Fig. 3. Although the points fall sufficiently close to these curves for identification purposes, it can be seen that the pole of (010)—obtained as the mean of four positions, one for each twin member of the two measured grains—lies, on the 20-cm. scale, $6\frac{1}{2}$ mm. from the (010) curve, being displaced from it in the direction of β. The [001] direction is displaced (for the same scale), in the same sense, 3 mm. from its appropriate curve. (The [001] axis is obtainable as the common direction of the oriented rod-shaped inclusions—see below.) The (001) cleavage could be recognized only as discontinuous and somewhat curved traces in one twin member of one grain. Thus the position of the (001) pole is only approximate; it has been plotted merely to check its identity and to obtain a reference from which the a-axis can be located.

The large, systematic deviations of [001] and particularly of (010) from their

[1] W. Nikitin, *Die Fedorow-Methode*, Berlin, 1936, pl. 6.



α, β, γ, refer to first twin member

$\alpha_1, \beta_1, \gamma_1$, refer to second twin member

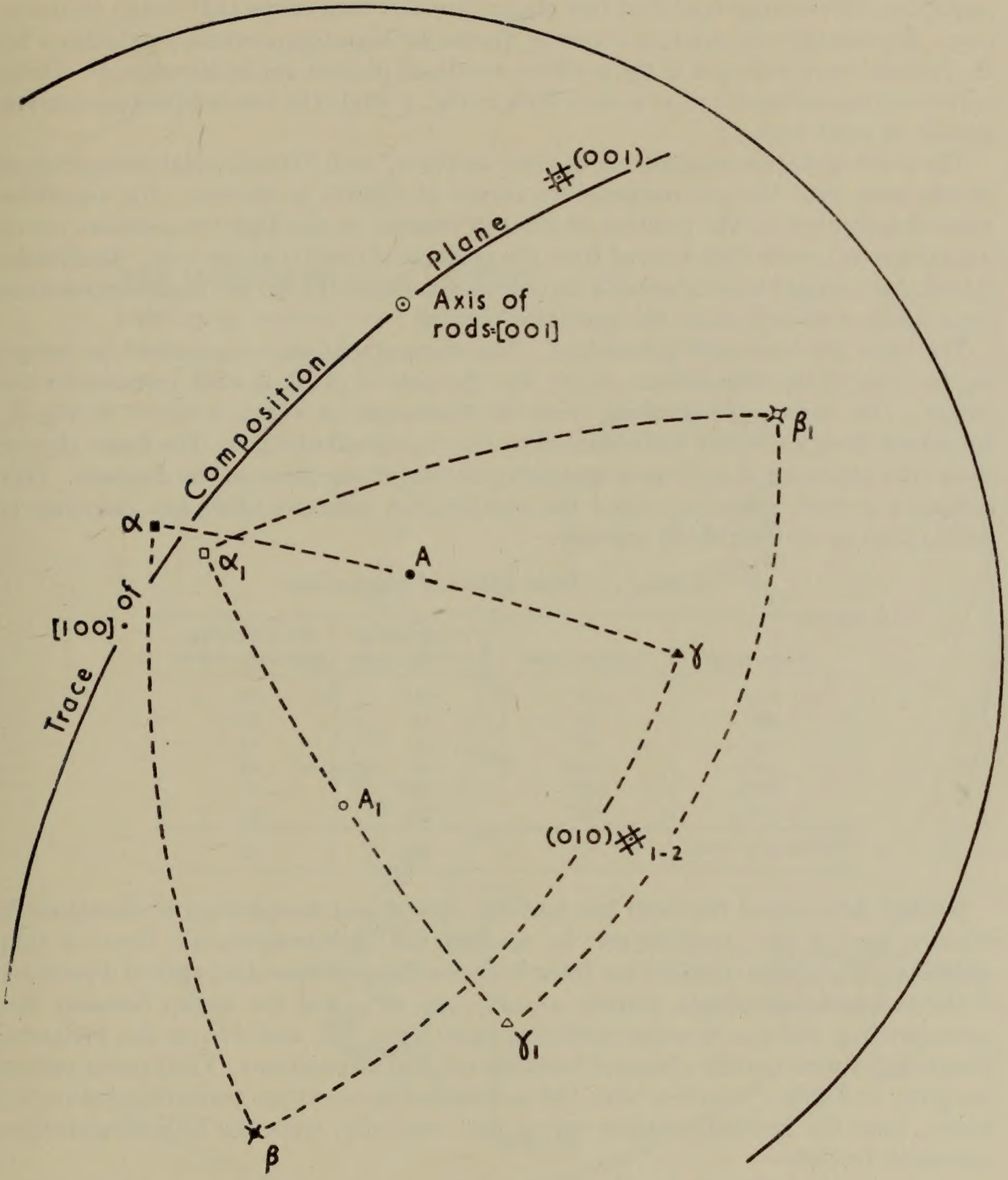
Broken lines show symmetry planes of indicatrix

A = optic axis of individual 1

A_1 = " " " " 2

(010)$\divideontimes_{1-2}$ = pole of composition plane = pole of (010) cleavage

Fig. 1.



The symbols have the same significance as in Figure 1.

FIG. 2.

respective curves suggested that this plagioclase had been subjected to high temperature. Accordingly the migration curves drawn for high-temperature plagioclases by H. Tertsch[1] were enlarged to the scale required and plotted on the stereogram. These curves are represented by the broken lines in Fig. 3, while the low-temperature curves appear as solid lines.

The much closer correspondence of (010) and [001] with Tertsch's high-temperature curves than with the low-temperature curves of Nikitin is obvious. The anorthite content indicated by the position of (010) in relation to the high temperature curve is 42 per cent., while that derived from the position of [001] is 43 per cent. As already stated (001) cannot be located with an accuracy sufficient to test the high-temperature hypothesis or to determine the anorthite content.

The twin law was next determined. The stereograms were transposed by bringing the pole of the composition plane, viz. the pole of (010), in each instance to the centre. The stereogram resulting from the transposal of Fig. 2 is shown in Fig. 4. An almost identical result was obtained by the transposal of Fig. 1. The figure clearly shows the existence of an axis of symmetry normal to the plane of the diagram. This indicates normal twinning; since the composition plane is (010) the twinning is determined as albite in both crystals.

TABLE 1. *Twin optics of plagioclase*

Twin angle	*Angular value*	*An. percentage low-temp. curve*	*An. percentage high-temp. curve*
$\alpha\alpha_1$	170°	42½	45
$\beta\beta_1$	57°	74	42
$\gamma\gamma_1$	58°	54	43
AB_1	42½°	49	43
BB_1	106°	49	41
$2V_{(\gamma)}$	85°	41½	43
Mean An. value	—	52	43

Having determined the twin law and the optical and morphological directions it remains to use the 'twin-optics' to confirm the high-temperature form of this andesine. The angles required are those between the corresponding optical directions of the twinned individuals, namely $\alpha\alpha_1$, $\beta\beta_1$, $\gamma\gamma_1$, $2V_{(\gamma)}$ and the angles between the corresponding and the non-corresponding optic axes, BB_1 and AB_1 in this instance. These angles were readily obtained from the original stereograms. Their mean values are given in Table 1, together with the corresponding anorthite percentages derived, firstly, from the low-temperature curves and, secondly, from the high-temperature curves of Tertsch.

As the table shows, the consistency of the anorthite percentages, read from the high-temperature curves, is in sharp contrast to the fluctuations which result from interpolation on the low-temperature curves. The mean anorthite value, derived from the high-temperature curves, namely 43 per cent., agrees with the values previously obtained from the stereograms.

The evidence that this plagioclase is of the high-temperature form is conclusive.

[1] H. Tertsch, 1942, Zur Hochtemperatur-Optik der Plagioklase. *Zbl. Min. Geol. Paläont.* Abt. A: 141.

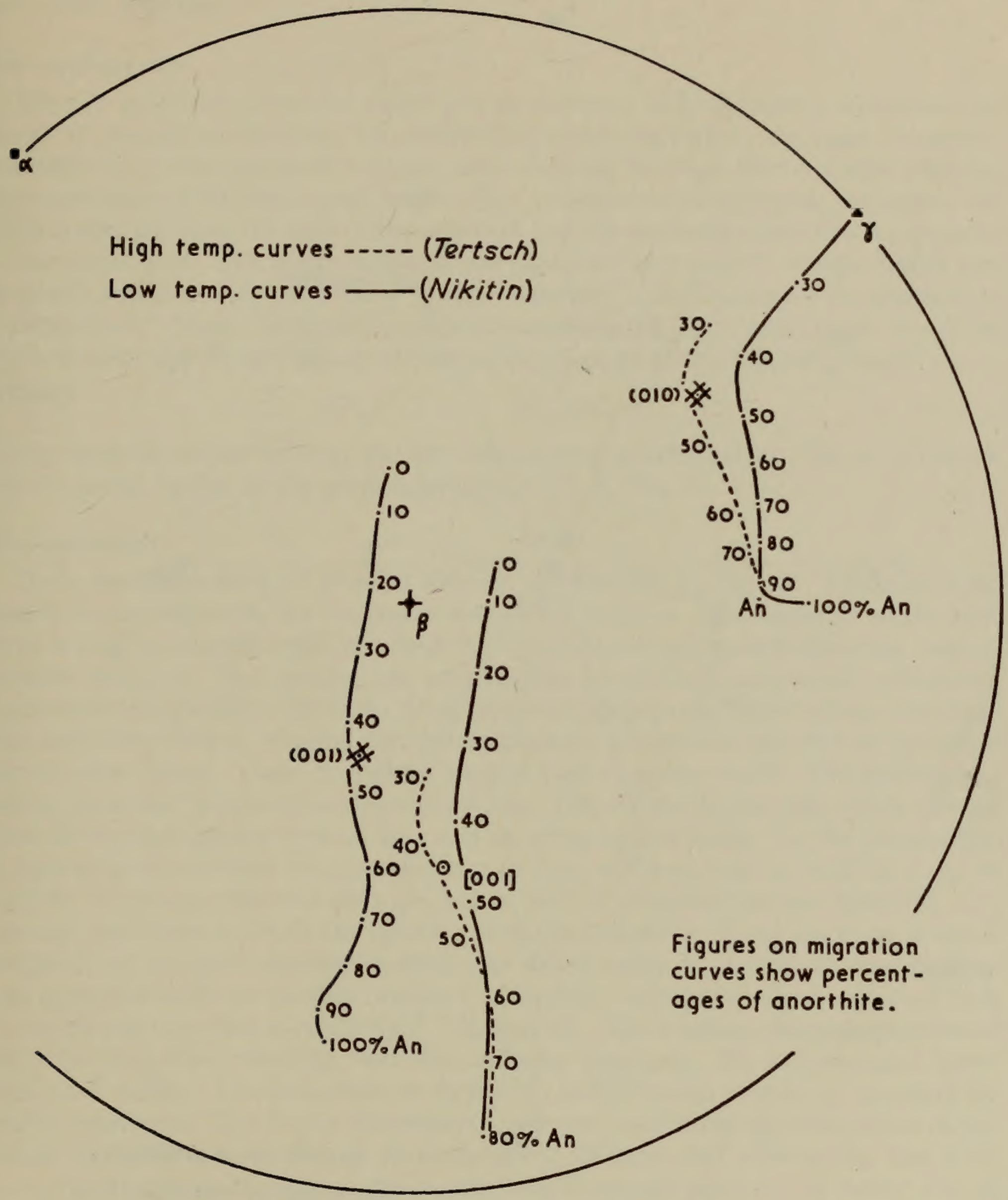
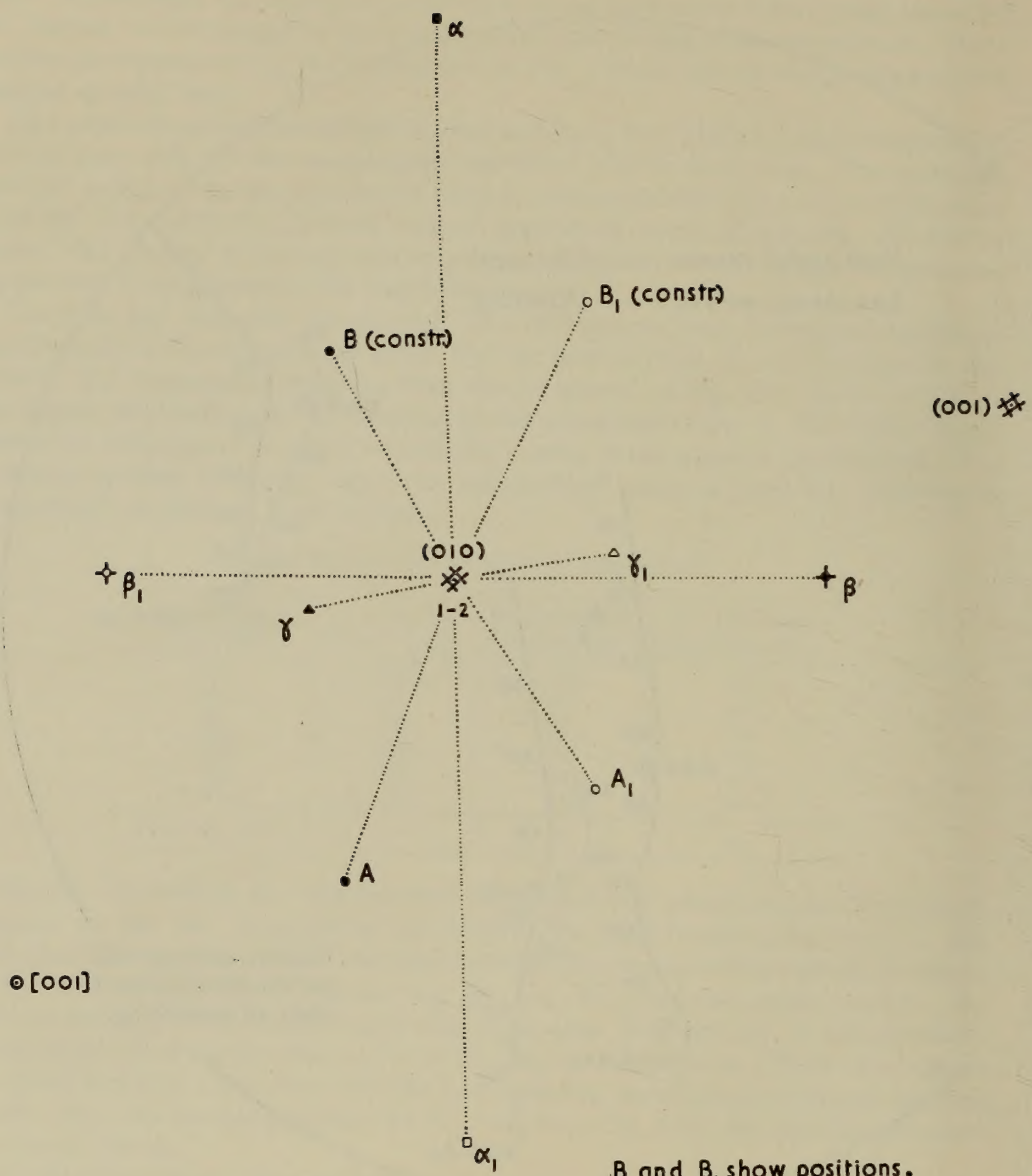

α
γ
β
High temp. curves ----- (*Tertsch*)
Low temp. curves —— (*Nikitin*)
(010)
(001)
[001]
An
100% An
80% An
Figures on migration curves show percentages of anorthite.

FIG. 3.



The symbols have the same significance as in Figs. 1 & 2.

B and B_1 show positions, obtained by construction, of the second optic axis of each twin member.

FIG. 4.

The 'host' may thus be described as a calcic andesine with high-temperature optics and albite twinning.

The reaction rim

The rim is of fairly constant width (0·1 to 0·2 mm.) and completely surrounds the group of plagioclase crystals. Its orientation is not everywhere the same, however; measurements were confined to those parts showing cleavage traces and/or allowing determination of the optic axial angle. Fig. 5 shows in stereographic projection the relationship between the pole of the cleavage and the indicatrix and also the position of one optic axis. The angle between cleavage pole and γ is 7°, which closely corresponds with the value of 5° for $\gamma{}^\wedge\perp(010)$ obtained from Emmons's stereogram for anorthoclase.[1] Three independent measurements of the optic axial angle (made on sections allowing the setting-up of both optic axes) gave the following results:

$$2V_{(\alpha)} \quad . \quad . \quad . \quad 66°, 65°, 63°.$$

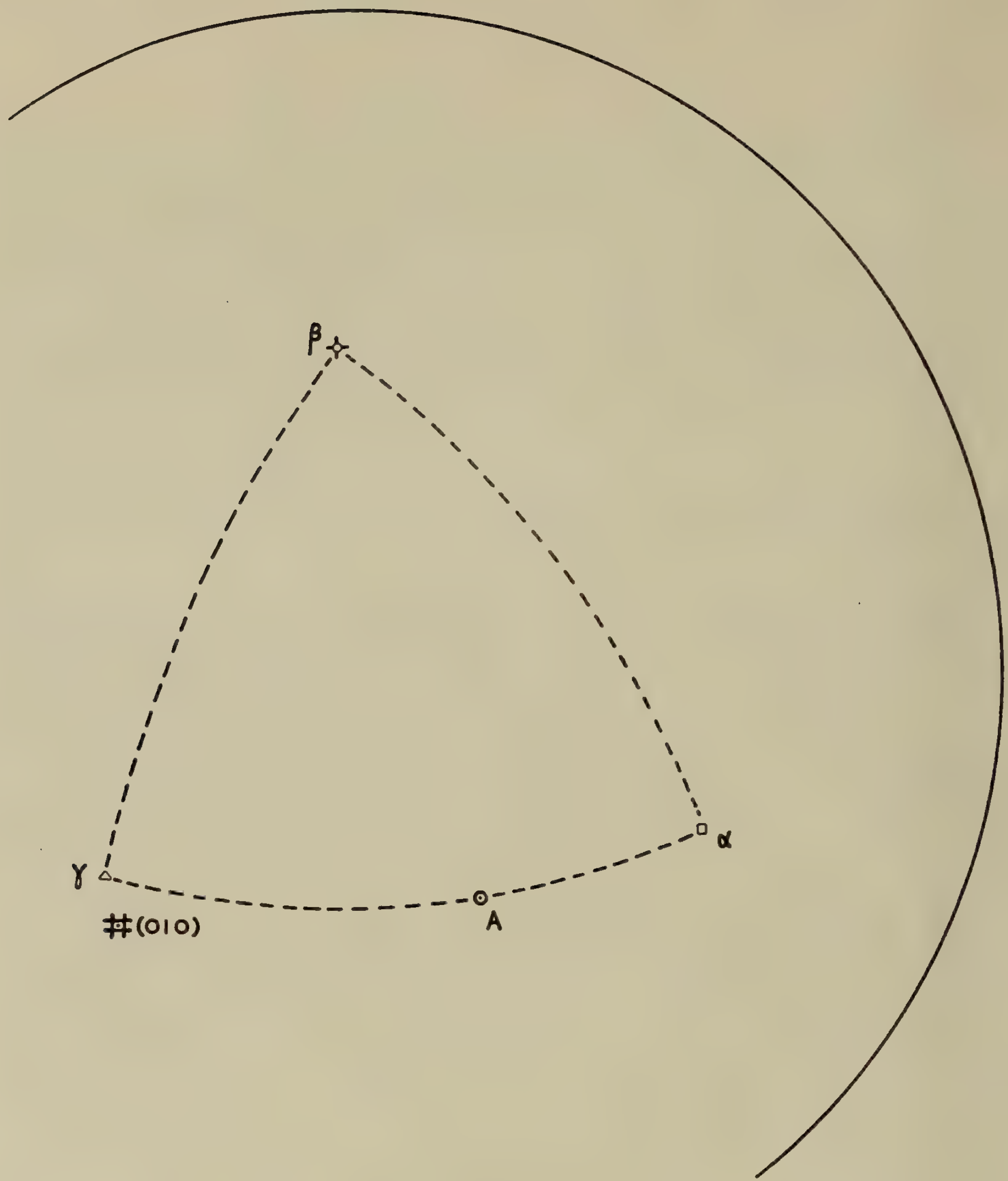
These determinations confirm the identification of anorthoclase. The anorthoclase rim is clearly visible in the photomicrograph (Pl. 5, Fig. 2).

The inclusions

These have the form of parallel rods or needles (Pl. 5, Fig. 1). The maximum length is 0·09 mm. and the maximum breadth 0·005 mm. The majority of the rods have a length:breadth ratio of about 60:1, but in the stumpiest rods this ratio is reduced to 13:1. The needles are mostly transparent and practically colourless. Some show considerable corrosion. They have very strong relief (due to their extremely high refractive index), straight extinction, positive elongation, and first-order yellow interference colour. These properties suggest that they are rutile. The interference colour, however, seems to be abnormally low. The widths of the rods which showed these first-order colours were of the order of 0·004 to 0·005 mm. On the assumption of equant cross-sections the birefringence is 0·09, whereas that of rutile is 0·29. It may be, of course, that the rods are not equant in cross-section but flattened. An attempt was made to check the identity of the inclusions by X-ray analysis. A small fragment of the host showing a relatively dense array of inclusions was isolated and mounted with the needles oriented vertically. A rotation photograph of long exposure was then taken by Dr. G. F. Claringbull. The resulting photograph showed only the layer-lines resulting from the andesine *c*-spacing. No intermediate layer-lines were visible. The proportion of inclusions in the host is obviously too small for visible reflections. The X-ray photograph, however, confirmed the orientation determined by optical methods. A spectrographic analysis was also made, but with inconclusive results.[2] Some of the needles show opaque patches, no doubt due to

[1] R. C. Emmons, 1943, The Universal Stage, *Mem. Geol. Soc. Amer.* **8**, pl. 12, fig. 9.

[2] Hand-picking of fragments containing a reasonable concentration of oriented needles yielded a total sample of less than 1 mg. A spectrographic analysis made on this sample by Dr. Webb of the Imperial College disclosed the presence of titanium lines. Unfortunately, however, it was found that titanium was a constituent of the plasticine used for sealing the ampoule in which the sample had been placed. Since the fragments were not entirely free of plasticine the results must be regarded as inconclusive. It is hoped to repeat the test if more material can be obtained.



The symbols have the same significance as in the preceding figures.

$$\gamma \,\hat{}\, \perp (010) = 7^\circ$$

$$2V_{(\alpha)} = 65^\circ$$

Fig. 5.

alteration, the alteration product being, possibly, ilmenite. Others are completely opaque. The identity of these latter is uncertain. The largest of them show terminal forms, which, under magnifications of the order of 1,000,[1] are seen to consist of a basal plane and pyramids. Approximate angular measurements, made on flat lying needles in (010) cleavage flakes, suggested a symmetry lower than orthorhombic. These measurements are, however, subject to considerable uncertainty on account of the practical difficulties. A search of the literature revealed no record of oriented rutile in feldspar; but ilmenite needles enclosed in labradorite and lying parallel to each other and to the *c*-axis of the host have been described from the Shitomir district of Poland by P. N. Chirwinsky.[2] Such an arrangement is more easily comprehended in the case of ilmenite, which has a *c*-spacing of about 14 Å (almost exactly twice the *c*-spacing of the calcic feldspars), than in the case of rutile, in which the *c*-dimension, 2·89 Å, bears no obvious relation to that of the plagioclases. It is possible that the opaque rods are, in fact, ilmenite. But it seems most unlikely that the rutile has been derived therefrom.

Summarizing, it seems possible that the great majority of the oriented inclusions are rutile; there is, however, a minority of opaque inclusions, the identity of which is uncertain. Both types of inclusion are mutually parallel.

Orientation of the rods

This was measured on the universal stage during the determination of the plagioclase. The axes of the rods were set vertically (coincident with the axis of the microscope). This was done for various different settings of the N-, H-, and K-axes,[3] and the mean position was plotted on the stereogram of the points thus obtained. The direction of the axes of the rods is shown in the stereograms (Figs. 1 and 2). In both figures it is seen to lie in the composition plane. In order to determine whether this axis corresponded with any crystal direction within this plane the position of the axis was inserted on the transposed stereograms having β at the centre, and these were then superimposed in turn on a set of migration curves (Reinhard's curves amended by Nikitin) to which had been added the corresponding curves for high-temperature plagioclases published by Tertsch.[4] The comparison was made for each twin member of the two different sections, viz. four times. Fig. 3 (compounded as the mean of the four resulting figures) clearly shows the coincidence of the axis with the [001] curve for high-temperature andesine having an anorthite content of 43 per cent.; this, as already shown, is the approximate composition of the plagioclase. The angle measured on the stereogram, between the axis and the (100) direction, is 65°. The supplement of this angle 115° corresponds with the value of the axial angle β for andesine, viz. $116\frac{1}{2}°$ approximately. This close agreement provides additional confirmation that the rutile rods are oriented parallel to the *c*-axis of the andesine host.

[1] A Powell & Lealand No. 1 microscope with rotating stage and an oil immersion Zeiss 3 mm. apochromatic objective of N.A. 1·4 was used.

[2] P. N. Chirwinsky, 1925, Avanturinlabrador aus Poromowka, Shitomir-Distrikt, Gouv. Wołynien. *Z. Krystallogr.* **62**: 139.

[3] Notation of M. Reinhard.

[4] W. Nikitin, *loc. cit.*; H. Tertsch, *loc. cit.*

I wish to thank my colleagues Messrs. W. N. Croft and R. Ross for the loan of the microscope and objectives for high-power magnification and for their help; I am grateful to Messrs. D. L. Williams and R. T. W. Atkins for the photographs and diagrams respectively. My thanks are also due to Dr. J. S. Webb for the spectrographic work and to Dr. W. Campbell Smith for criticism and advice.

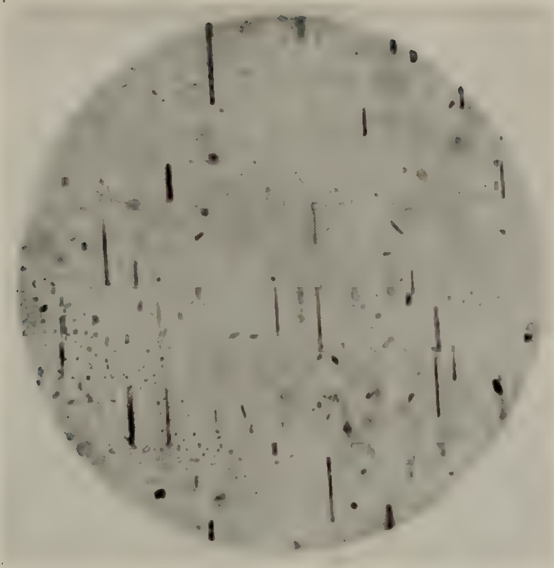


FIG. 1. Oriented rutile needles in Andesine
Ordinary light; ×250

FIG. 2. Andesine showing Albite twinning and reaction rim of Anorthoclase
Polarized light; ×50

NOTE ON ANORTHOCLASE FROM NIGERIA

By J. R. F. JOYCE *and* P. M. GAME

(*With Plate* 6)

THE anorthoclase which is the subject of this account occurs as large rhomb-shaped phenocrysts in a soda-trachyte. This rock outcrops on the steeper eastern and southern flanks of a gently sloping hill, which rises about 200 feet above the general level of the plateau, in latitude 9° 23′ N., longitude 8° 58′ E. near the centre of Nigeria, in the Plateau Province.

The specimens were collected in 1942 by the first-named author and presented to the Museum in 1949 (registered number B.M. 1949,25). At the time of this visit it was not realized that the rock had not previously been described and the outcrop was not examined in detail. The largest crystal collected measures about $10 \times 4\frac{1}{2} \times 6$ cm., but much larger specimens occur.

These anorthoclase phenocrysts, together with microphenocrysts of soda-pyroxene, are embedded in a trachytic groundmass of anorthoclase prisms showing well-developed flow structure. The presence of xenocrysts of andesine and spongy areas of quartz, riebeckite, and magnetite is evidence of the contamination of this rock from at least two different sources. The anorthoclase prisms of the groundmass are twinned on the Carlsbad law; $\gamma = 1{\cdot}536$; $2V_{(\alpha)} = 57°$ (mean of seven determinations). The andesine xenocrysts have the composition $Ab_{57}An_{43}$ and contain rod-like inclusions, probably rutile, which lie parallel to one another and to the *c*-axis of the feldspar. These andesines are surrounded by a rim of anorthoclase 0·1 to 0·2 mm. wide.

TABLE I. *Chemical Analysis*

Anorthoclase from central Nigeria (B.M. 1949,25). (Analyst J. R. F. Joyce)

Analysis		*Atomic ratios*		*No. of metal atoms on basis of 32 O*	
SiO_2	65·86	Si	1·0975	11·66	
Al_2O_3	20·66	Al	0·4051	4·30	16·00
Fe_2O_3	0·29	Fe	0·0036	0·04	
FeO	0·10	Fe	0·0014	0·02	
MnO	Tr.				
MgO	0·12	Mg	0·0030	0·03	
BaO	0·12	Ba	0·0008	0·01	4·01
CaO	1·50	Ca	0·0268	0·28	
K_2O	3·88	K	0·0825	0·87	
Na_2O	8·17	Na	0·2635	2·80	
H_2O	0·17	O	3·0130		32·00
	100·87				

Sp. gr. (d_4^{20}) $2{\cdot}587 \pm 0{\cdot}010$ (by floatation method, using mixtures of bromoform and alcohol).
Molecular composition; Or 22·6, Ab 72·3, An 4·9, Cn 0·2 per cent.

Chemical composition

The chemical analysis of a hand-picked sample of the feldspar of the phenocrysts is given in Table 1, together with the atomic ratios and unit cell contents, calculated

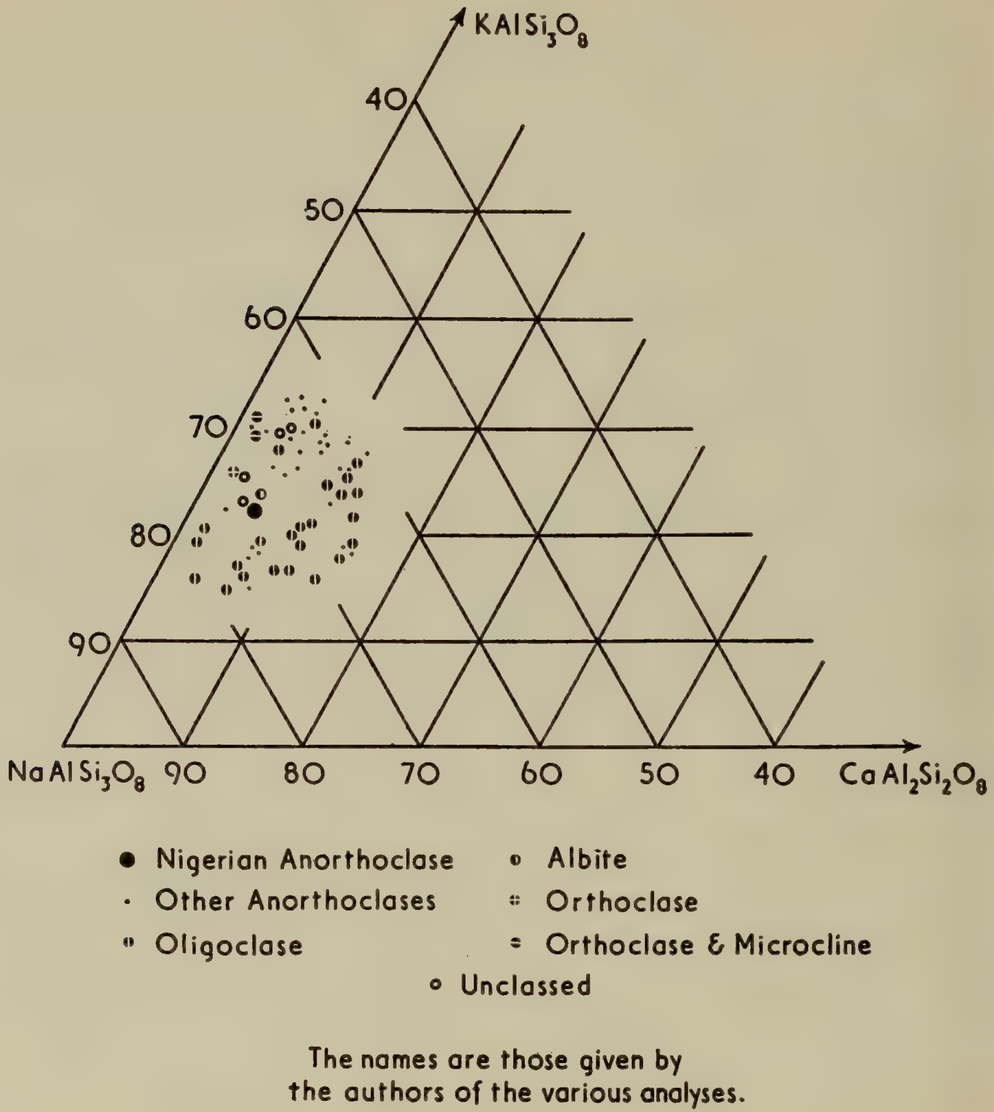


Fig. 1.

on a basis of 32 oxygen atoms. The analysis shows that the feldspar falls well within the anorthoclase field having the composition $Ab_{72\cdot3}Or_{22\cdot6}An_{4\cdot9}$. It contains 0·2 per cent. of the celsian molecule. In Fig. 1 the composition is shown in the form of a triangular diagram, in which plots of analyses of similar feldspars have been included.

The diagram shows that feldspars of comparable composition have mainly been termed anorthoclase or oligoclase by those who described them.

Optical properties

Table 2 gives the result of the optical determinations.

TABLE 2. *Optical Data*

α	= 1·5275 (Na-light)
β	= 1·5334 ,, ,,
γ	= 1·5349 ,, ,,
$2V_{(\alpha)}$ (measured)	= $52\frac{1}{2}°$ [$\rho > V$]
$2V$ (calculated from values of α, β, and γ)	= 53° 18′
(001) ^ (010)	= 89° 09′
α' ^ (001) on (010) cleavage flakes	= 5°·9 (mean of 9 values ranging from 4°·6 to 6°·8)
α' ^ (010) on (001) cleavage flakes	= 0°·8 (mean of 3 values ranging from 0°·0 to 1°·8)
α ^ [100]	= 8°
γ ^ [010]*	= 5°

* The position of [010] was obtained on the assumption of a value for the interfacial angle (001) ^ (100) of 116°.

Refractive indices were determined on polished surfaces in sodium light and with an Abbé-Pulfrich refractometer, previously calibrated against glass of known index and against quartz.

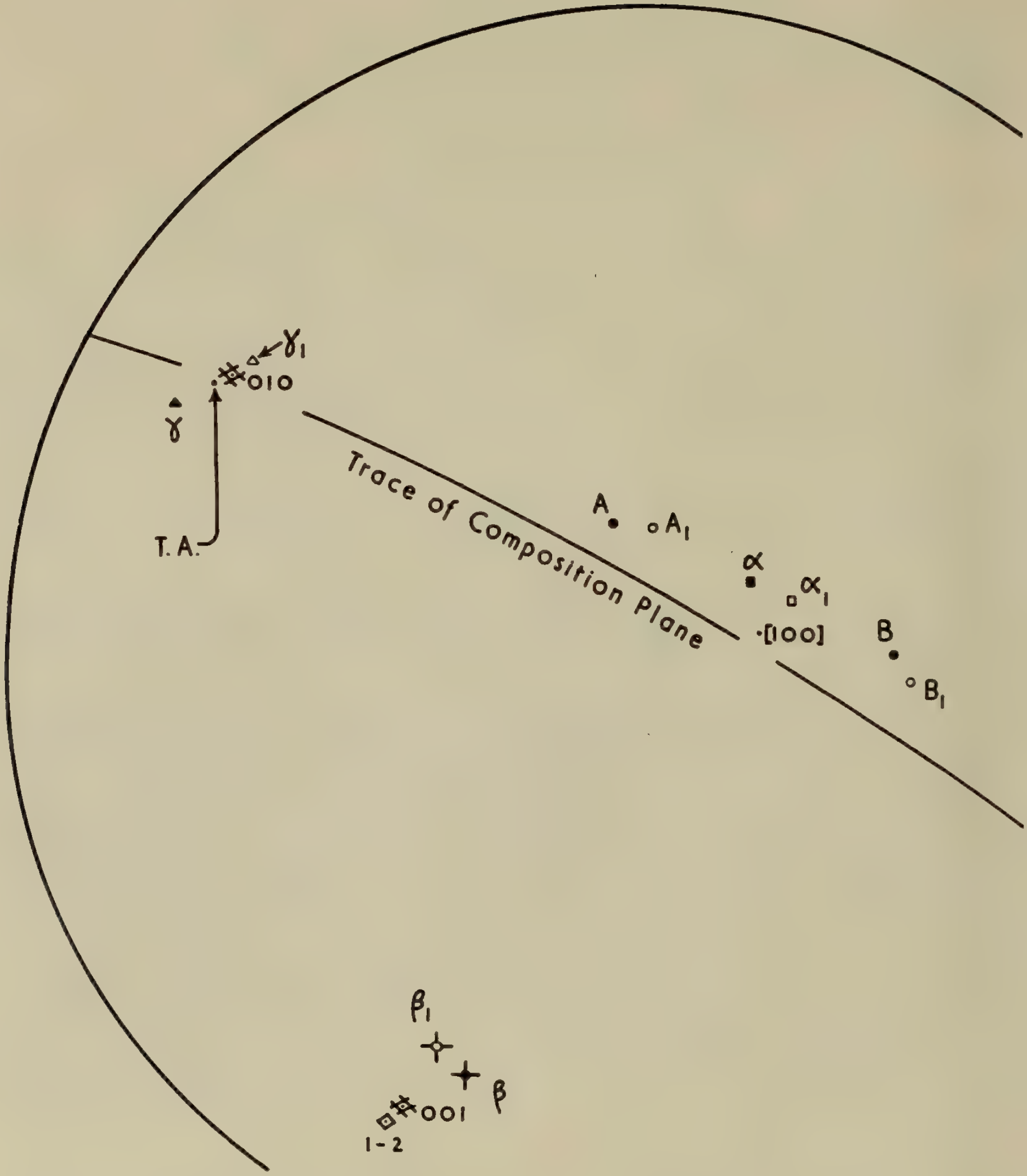
The value given for the cleavage angle was obtained as the mean of five determinations on a selected fragment using a Fuess single-circle goniometer. Good signals were obtained from (001), but signals from (010) were less precisely defined.

Extinction angles were measured on flakes obtained from a crushed sample. (010) was found to be the direction of easier cleavage; at least 90 per cent. of the cleavage flakes obtained by crushing were found to be (010) flakes. They can be recognized by means of their fine, polysynthetic twinning and centred, obtuse bisectrix interference figures. (001) represents a much harder cleavage; (001) flakes often show undulose extinction; hence the extinction angles obtained on these flakes show greater variations in value than do those measured on (010). Some (001) flakes show both relatively broad, rather hazy twin lamellae and also fine lamellae, both sets being parallel to the (010) cleavage face.

The determinations of the optic axial angle were made on a Leitz four-axis universal stage.

Optical orientation and twinning

Examination of a thin section (section 1) cut approximately perpendicular to both cleavages revealed the presence of two sets of twin lamellae almost at right angles to each other (Pl. 6, Fig. 1). One set of lamellae (parallel to (010)) are too fine to permit the determination of optic vectors, although it proved possible to orient the composition plane. The other set of lamellae (approximately parallel to (001)) are of sufficient breadth (maximum 0·08 mm.) to allow their optical orientation to be determined on the universal stage. Some of these relatively broader lamellae are homogeneous, but



A and B = optic axes of individual 1
A_1 and B_1 = " " " " 2
T. A. • = twin axis

◇ 1-2 = pole of composition plane
✣ 010 = pole of (010) cleavage
✣ 001 = pole of (001) cleavage

FIG. 2.

others show very fine striations (Pl. 6, Fig. 2), parallel to the wider ones, which had to be disregarded in making the optical measurements. The stereogram of this section is shown in Fig. 2. When the plot of the first twin member is transposed so as to bring γ to the centre, the resulting positions of the poles of (001) and (010) (see Fig. 2*a*) closely correspond with the positions given by Emmons[1] for anorthoclase.

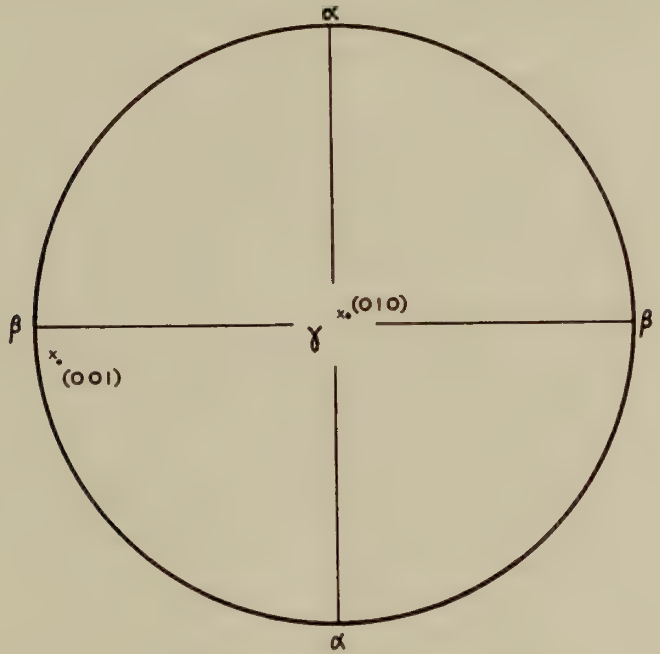


FIG. 2*a*.

The location, in the stereogram, of the twin axis in the composition plane is evidence of a parallel or complex twin law. Assuming an interfacial angle (001) ^ (100) of 116° it is possible to plot the zone axis [010] which lies at the intersection of the traces of the (001) and (100) planes. It is then found that [010] is, within the limits of plotting error, coincident with the twin axis. The stereogram also shows that the composition plane lies close to but does not coincide with (001), the angle between the two poles being about $2\frac{1}{2}°$. The twin axis lies within about 1° of the pole of (010). The evidence therefore indicates pericline twinning, the composition plane forming an angle of 2° to 3° with the (001) plane is the obtuse angle β (viz. $+2°$ to 3° adopting the usual convention). Confirmation of the orientation of this composition plane was obtained by examining a section parallel to (010). On this section the trace of the composition plane was observed to make an angle of 3° with the trace of the (001)

[1] R. C. Emmons, 1943, The Universal Stage, *Mem. Geol. Soc. Amer.* **8**, pl. 12, fig. 9.

cleavage. This angle differs by 9° from the mean angle quoted by Winchell[1] for pericline twins in anorthoclase, viz. −6°.

The orientation of anorthoclase is close to that of an oligoclase containing about 21 per cent. An. When therefore the stereogram (Fig. 2), after transposal to bring β to the centre, is superimposed on the appropriate Reinhard[2] diagram, the pole of (001) falls within 1 mm. of the migration curve for this pole (on the 20-cm. scale), whereas the (010) pole falls about 8 mm. below the (010) migration curve. From orientation measurements alone the distinction between anorthoclase and oligoclase might be open to doubt. Measurements of refractive indices and of $2V$ would, however, always distinguish between the two. The pericline composition plane for an oligoclase with 21 per cent. An would make an angle of about 6° with (001), a value not very different from that obtained for this anorthoclase, viz. +3°.

In section 1 (represented by Fig. 2) it was impossible to measure the optical orientation of the twinning lamellae which are perpendicular to the pericline lamellae and parallel to (010) because, as already stated, they are too narrow. However, a section approximately parallel to (001) (section 2) yielded some lamellae of sufficient width (up to 0·1 mm.) for optical determinations. Some of these relatively broader lamellae, like the pericline lamellae, show very fine parallel striations; others, while showing no twinning which can be resolved with the microscope, yet give incomplete or hazy extinction. The optical orientations of different pairs of twin lamellae in this section are not identical. The differences measured in three different pairs are shown in the three stereograms (*a*), (*b*), and (*c*) of Fig. 3. In the twin members represented by Fig. 3 (*a*) the extinction is approximately symmetrical with respect to the composition plane (010) and γ is inclined to the normal to (010) at 5°, this being the approximate value of the symmetrical extinction angle. In Fig. 3 (*b*) the extinction angles are still symmetrical but γ for each member of this twin pair is almost coincident with the normal to (010); the extinction angle is therefore almost zero. Fig. 3 (*c*) shows that this pair of twin lamellae have asymmetrical extinction. For one individual the value of $\gamma \wedge$ (010) is 6° while for the other it is almost zero. Extinction angles differing by 5° or 6° were observed in several twin pairs.

Fig. 3 (*d*) shows the stereogram of Fig. 3 (*a*) transposed so as to make the composition plane the plane of projection. The disposition of poles demonstrates the existence of a twin axis perpendicular to the plane of the figure, viz. perpendicular to (010), and shows that the twinning is albite.

The anomalous variations in the angles between conjugate poles for different twin pairs in the same section and the occasional asymmetrical extinction angles are thought to be due to the presence of submicroscopic twin lamellae in varying proportions (i.e. of different widths) in different lamellae.

A relatively broad lamella which is made up of fine (invisible) twin pairs of equal width would be expected to show (in the section perpendicular to (010) which we are considering) straight but incomplete extinction (Fig. 3 (*b*)). If, however, the visible lamella is composed of pairs of finer lamellae of very different widths, then its overall optical orientation will accord with that of the predominant member of these pairs.

[1] A. N. Winchell, *Elements of Optical Mineralogy*, 3rd edit., New York, 1933, part ii, p. 326.

[2] M. Reinhard, *Universal Drehtischmethoden*, Basel, 1931, pl. 2 [M.A. 4–435].

The extinction angle shown by the lamella then approaches the true value for this section. Asymmetrical extinction angles may then be explained by the different submicroscopic make-up of the two adjacent lamellae. Adjacent visible lamellae may thus show variations in both the size and symmetry of their extinction angles due to variations in the proportions of their invisible components.

The authors wish to express their best thanks to Dr. M. H. Hey both for supervising the analysis and for help in discussing the problem of anomalies in the twinning.

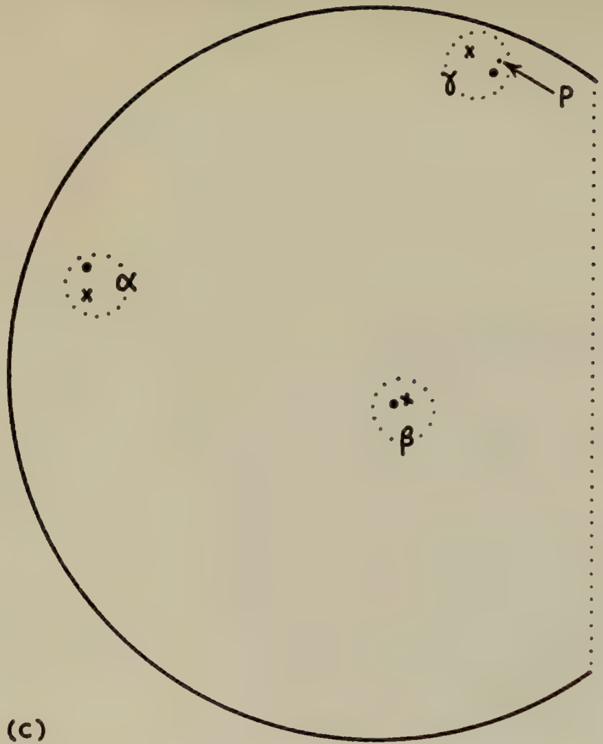
(a)

First pair of twin lamellae: joint width ·04 mm.
extinction sharply defined, symmetrical.

(b)

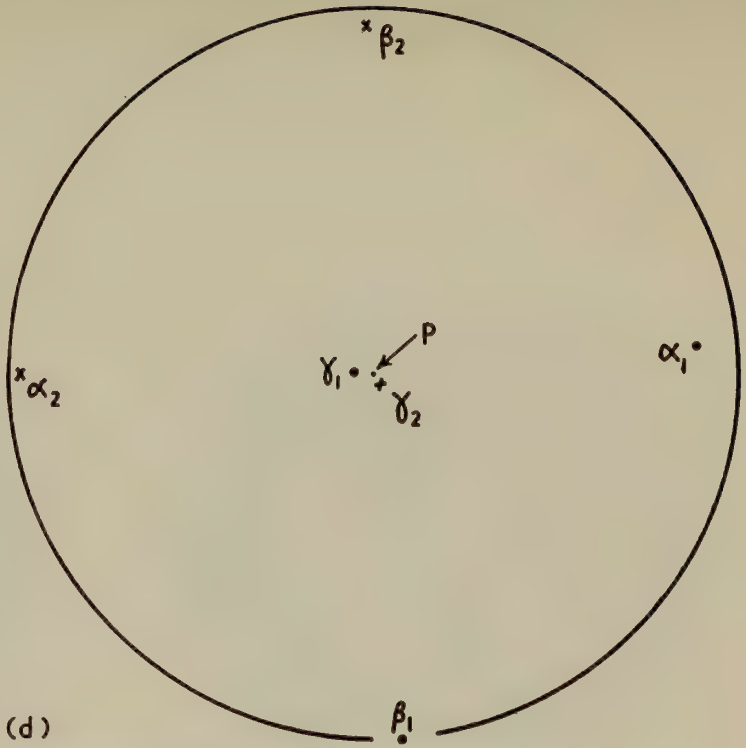
Second pair of twin lamellae: joint width ·45 mm.
extinction incomplete, symmetrical.

• = poles of twin member 1
× = " " " " 2
P = pole of composition plane



(c)

Third pair of twin lamellae: joint width ·10 mm. extinction asymmetrical



(d)

Transposed stereogram of figure 3(a). Plane of projection is the composition plane (010). Twin law is [Albite law.

• = poles of twin member 1
x = " " " " 2
P = pole of composition plane

FIG. 3.

FIG. 1. Anorthoclase; section inclined at 20° to [100]
Polarized light; ×50

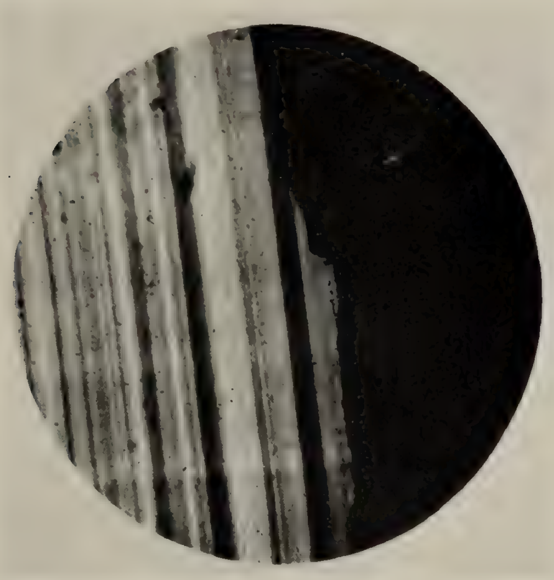


FIG. 2. Anorthoclase; same section as fig. 1, showing twin lamellae parallel to (001)
Polarized light; ×50

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